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Abstract

One of the main challenges in Eddy Current Testing (ECT) is the solution of the inverse problem, i.e., the determination of the defect properties knowing the measured data. To this end, many approaches and mathematical tools have been proposed. The so-called adaptive database-method has recently been developed. Its main idea is to store corresponding input-output data pairs in a database and, by fitting an interpolator to these samples, to solve approximately the forward and inverse problems at a low computational cost. Such adaptive databases can be generated by meshing methods [1, 2] (inspired by the meshes of Finite Element Methods) or meshless approach as introduced in [3] and recast and extended in [4].

The sampling strategy of the database generation presented in [4] has been improved and will briefly be described, however the presentation will mainly be focused on the application of such adaptive databases for the characterization of the related inverse problem.

For a formal description, let us define a defect model with p parameters by the vector $\mathbf{x}=[x_1, x_2, \ldots, x_p]^T$ (usually position and dimensions of the defect), whereas the functional output (the measured data) can be the impedance variation $\Delta Z(s)$ of the probe coil, where s is related to the position of the coil. The input and the output are connected by the forward operator F: $\Delta Z(s)=\mathsf{F}\{\mathbf{x}\}$. One can also assign a p dimensional region $\mathcal{X}$, called the *input space* so that for all conceivable input vectors $\mathbf{x}\in\mathcal{X}$ holds. The co-domain of the operator F over $\mathcal{X}$ is the *output space* $\mathcal{Y}$, i.e., $\mathsf{F}: \mathcal{X}\rightarrow\mathcal{Y}$.

The goal of our adaptive sampling is to generate a set of n samples $(\mathbf{x}_i, \Delta Z_i(s))$, $i=1,2,\ldots,n$, such that the outputs $\Delta Z_i(s)$ are as far as possible from each other and such that all conceivable outputs are closer to at least one stored sample than a pre-defined limit (in the sense of an appropriate norm). The output space is then evenly sampled leading to an "equidistant" output sampling. In the first version [4] the database generation procedure was an iterative-incremental loop, adding samples one-by-one according to some criteria based on the distances in the output space. In the present version a removing strategy has been added in order to make the sampling more uniform. Intuitively, such an incremental-iterative loop is supposed to converge to an output-equidistant database.

As a first application, the combination of an optimal database and a simple interpolator (nearest neighbor for example) allows us to predict the solution $\Delta Z(s)$ for a sample $\mathbf{x}$ which does not belong to the database –in a very short time. But the structure of such a database is also able to provide some meta-information about the involved forward operator F. As a matter of fact, in the regions of $\mathcal{X}$ where F varies rapidly, the sampling will be dense, whereas in the regions where F varies slowly the sampling will be sparse. With such information the related inverse problem can be characterized to some extent. On one hand, the

defects related to flat regions of F are hard-to-characterize from the measured data, the problem tends to be ill-posed. On the other hand, in the case of a defect corresponding to fast variations of F, a more precise reconstruction is possible. These qualitative considerations are formalized in the paper, enabling us to draw also quantitative conclusions about the inverse problem.

Two approaches are presented, both of them being related to some kind of inverse mapping –regions of the output space $\mathcal{Y}$ are projected back onto the corresponding regions of the input space $\mathcal{X}$.

The first method focuses on the noise-level which might corrupt the measured data leading to an uncertainty about the solution of the inverse problem. One has then to consider a region of $\mathcal{Y}$ around the measured data. The size of this region, or "noise cell", depends on the noise level. By projecting back this noise cell onto the input space $\mathcal{X}$, the uncertainty of the inversion can then be expressed as the size of the resulted image in the input space.

The second method is based on the partition of the output space $\mathcal{Y}$ into a more-or-less uniform subregions using the database samples and their related so-called Voronoï cells defined by a well-chosen norm. The inverse mapping of these output Voronoï cells onto the input space leads to an explicit expression of the attainable precision in the solution of the inverse problem using a combination of the adaptive database and a nearest neighbor interpolator.

Both approaches are illustrated by examples using a numerical simulator combining a surface integral method and the so-called "global approximation" [5]. Beyond the presented ECT-oriented applications, the tools might be useful in other domains of electromagnetic nondestructive evaluation as well.

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